Cadaveric Study for Skull Base Reconstruction Using Anteriorly Based Inferior Turbinate Flap

Moran Amit, MD; Jacob Cohen, MD; Ilan Koren, MD; Ziv Gil, MD, PhD

Objectives/Hypothesis: To demonstrate the feasibility of an anteriorly pedicled inferior turbinate flap (AITF) as a method for endoscopic reconstruction of anterior skull base defects in the absence of a nasal septal flap.

Study Design: Cadaveric feasibility study.

Setting: University-affiliated tertiary medical center.

Materials and Patients: A cadaveric model was used to investigate the feasibility of harvesting and skull base reconstruction with an AITF. The size and extent of coverage of the flap were investigated. Subsequently, defects resulting from an endoscopic resection of various anterior skull base pathologies were reconstructed with an AITF in patients.

Results: In the cadaveric model (n = 11), the mean length, width, and area of the AITFs were 4.76 ± 0.52 cm, 1.8 ± 0.34 cm, and 4.31 ± 0.87 cm², respectively. The flap provided a mean of 111 ± 12% (range 95%–133%) coverage of the anterior skull base from the posterior table of the frontal sinus to the sella. Following that experience, ten patients were successfully reconstructed with AITFs, and there were no postoperative cerebrospinal fluid (CSF) leaks or occurrence of meningitis.

Conclusion: The results of this study demonstrate the feasibility of AITFs for the reconstruction of anterior skull base defects in the absence of alternative vascularized flaps.

Key Words: Skull base, endoscopy, reconstruction, fascia lata, cerebrospinal fluid leak.

Level of Evidence: 4.

INTRODUCTION

Endoscopic surgery has rapidly expanded for treating benign and malignant diseases involving the anterior and middle skull base in the last decade. A significant pitfall of this approach has been the difficulty to reconstruct large dural defects. Failure to achieve adequate reconstruction can lead to a significant morbidity of cerebrospinal fluid (CSF) leak, pneumocephalus, and meningitis. Advances in multilayered reconstruction methods and the development of vascularized locoregional flaps, including the nasal septal flap (NSF), have improved our ability to seal the skull base. Moreover, utilization of the NSF has reduced the rate of complications to under 5%, and enabled an increasing number of patients with skull base neoplasms to undergo curative surgical resections with the use of minimally invasive techniques. However, the NSF is frequently missing due to previous surgery that had compromised its blood supply or when the septum is invaded by tumor. The absence of an NSF limits the ability to reconstruct the anterior skull base because of the paucity of alternative intranasal vascularized flaps that are long enough to cover the defect.

In this feasibility study, we describe the design of an alternative flap, the anteriorly pedicled inferior turbinate flap (AITF). The AITF, recently introduced by Hadad et al., exploits the dense vascular supply of the anterior ethmoidal artery (AEA). We show that this flap can be used alone, as well as in conjunction with posteriorly pedicled flaps for the reconstruction of anterior skull base defects. We believe that the AITF will be an important addition to our armamentarium of endonasal reconstruction techniques.

MATERIALS AND METHODS

The inferior nasal turbinate is an independent bone that is covered with a thick mucosa invested with a dense vasculature plexus. The nasolacrimal duct is situated lateral to the inferior turbinate and drains to the inferior meatus. The flap was designed to enable nasolacrimal duct preservation. The arterial blood supply of the inferior turbinate is derived from three main sources: the turbinate branch of the sphenopalatine artery (SPA), the AEA, and the lateral nasal artery (LNA), which is a branch of the facial artery. The posterior lateral nasal branches of the SPA supply the posterior half of the inferior turbinate mucosa. The anterior lateral branches of the AEA, together with branches from the LNA, carry its blood supply to its anterior half, as depicted in Figure 1. The anterior and posterior branches anastomose at the middle of the turbinate to form the inferior turbinate artery (ITA). The ITA often divides into a medial and lateral branch to provide a robust blood supply along the complete length on the inferior turbinate. In this area, the vessels increase in diameter, composing a significant anterior and posterior component of the blood supply of...
The anterior blood supply of the AEA is what allows an anteriorly pedicled flap design. We aimed to use the entire length of the inferior turbinate in all the cases described in this study. We originally designed the flap to reconstruct defects in the frontal sinus and cribiform plate and defects located between the ethmoid roof and the cribriform plate. A modification of the flap was designed so that it can increase its length by extending the vertical incision performed anteriorly to the turbinate, superiorly up to the level of the nasal bone, and then along its roof in a posterior direction toward the anterior wall of the frontal sinus (see Fig. 1). We used the modified version of the flap for the reconstruction of posterior defects, such as those in the sella and planum sphenoidale.18

Cadaveric specimens were used to design, harvest, and transpose several modifications of the anteriorly based inferior turbinate flap into various defects of the anterior skull base. Flap measurements were calculated as a percentage of anterior cranial fossa length measured before flap harvesting (Fig. 2). After midsagittal dissection of the specimens, a septectomy, excision of the middle turbinate, and sphenoethmoidectomy were performed to expose the anterior cranial fossa. Next, the AITF was raised bilaterally (Fig. 3), and the most anterior and inferoposterior extent that could be reached on the anterior skull base were recorded (Table I). The coverage was defined as a percentage of total anterior cranial fossa length (from the back wall of the frontal sinus to the sella).17 The flap was then harvested (Fig. 2b) in order to measure its dimensions. The width was defined as the widest measurement in the distal third of the flap.

The anatomic details and technical variations obtained from the cadaveric model provided us with enough information and confidence to use the flap clinically. The AITF flap was planned for patients who required EEAs and whose clinical presentation necessitated the use of the AITF. We performed a review of the demographic, clinical, surgical, and outcome data of the patients selected to undergo EEAs with skull base reconstruction using AITFs (as approved by the Institutional Review Board).

Tumor resection and reconstruction are performed via the EEA, as described elsewhere.20 The flap is elevated at the end of the operation; therefore, it does not obstruct the access during tumor removal. There rarely is a need to store the flap in the maxillary antrum until the reconstruction. After infiltration of the submucosa of the lateral nasal wall with lidocaine 1%...
and epinephrine $1/100,000$, the inferior turbinate is gently in-fractured. Then the caudal part of the middle turbinate on the side of the flap is resected. The AITF is elevated at this stage, and the entire portion of the inferior turbinate is harvested. A low vertical incision is made anterior to the head of the inferior turbinate, from the level of the nasal bone to the floor of the nose under direct endoscopic visualization (Fig. 4). At this point, care is taken not to injure the branches of the AEA, which pass anterior to the agger nasi. The AEA branches arc below the nasal bone and spine of the frontal bone in a C-shaped loop before entering the inferior turbinate.

If possible, a wide modified Lothrop procedure should be avoided since it may compromise the vascular supply of the flap. Next, the mucoperiosteum covering the turbinate is elevated in an anterior-to-posterior direction with the use of a Cottle elevator and endoscopic scissors. The flap is detached from its inferior and lateral attachments. The bone of the inferior turbinate is left in place for epithelialization, thus reducing the morbidity of this procedure. The AITF is now advanced toward the defect, where it is placed over the bare edges of the bone. The mucoperiosteum surface of the flap should face the dural defect. After positioning of the flap, the reconstruction is covered with strips of Surgicel (Ethicon, Inc, Johnson & Johnson, Somerville, NJ) and fibrin glue, followed by strips of Gelfoam sponge (Pfizer, Inc, NY, NY) to provide separation from the nasal packing. The reconstruction is supported with a sponge nasal packing, which is gently placed inside the nasal cavity. A lumbar drain is placed for 2 to 3 days in case of a high flow leak. The nasal packing is removed 7 days postoperatively. After removal of the bolster, the patient is instructed to irrigate the nasal cavity with saline every 3 to 6 hours. The patient is followed up bimonthly in an outpatient clinic for 2 months, and the nasal cavity is suctioned by the treating physician under endoscopic guidance. As nasal crusting subsides, the patient is instructed to maintain nasal irrigation on a daily basis for 12 months.

Statistical analyses were performed by assessment of coverage to skull proportions with a Pearson correlation coefficient. Descriptive data only were obtained for other outcomes. Calculations were performed with JMP Version 9 (JMP , SAS Institute Inc, Cary, NC). The Fisher exact test (StatCalc 2.0, University of Louisiana,

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Fovea Ethmoidalis Planum Sella

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AITF = anteriorly pedicled inferior turbinate flap; n = no; y = yes.

Fig. 4. An intraoperative picture taken with 30° endoscope, showing a left AITF. The flap was rotated to cover a large defect along the cribriform plate. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
Lafayette, LA) was used when the number of events was <10. Two-tailed calculations were performed in all statistical analyses.

RESULTS

A total of 11 cadaver heads (5 female heads) were suitable for use in this study. All cadaveric AITFs were harvested (as described in the Methods section) and rotated superiorly for reconstruction of anterior skull base defects. There was some tendency of the flap to return to its original shape, but this was easily overcome with gentle prodding. The harvesting, transposition, and rotation onto the skull base defect were successful in all the AITF procedures (Fig. 2). The mean length of the 22 flaps was $4.76 \pm 0.52$ cm, with an average width of $1.8 \pm 0.34$ cm and a mean surface area of $4.31 \pm 0.87$ cm$^2$ (Table I). The length and width of the flaps was adequate for covering the planum and fovea ethmoidalis in all cases. The average distance covered by the flap was measured from the anterior sella to the posterior wall of the frontal sinus ($4.28 \pm 0.3$ cm). The length of the flap was adequate to cover sellar defects in 17/22 flaps (Fig. 3). In the remaining five flaps, the maximal length was $4.14 \pm 0.18$ cm, which was too short to reach the sella (those flaps had a mean surface area of $3.52 \pm 0.84$ cm$^2$), so we utilized an extended AITF (Table II) in which the incision is extended superiorly and posteriorly toward the frontal recess (Fig. 1). This maneuver resulted in a flap extension to a mean length of $5.14 \pm 0.64$ cm, and the resultant mean coverage was $111 \pm 12\%$ (range, 95–133%) (Table I).

We then performed a chart review of ten patients who were planned to undergo endoscopic skull base reconstruction. Clinical and demographic data of patients reconstructed using the AITF is summarized in Table III. All flaps appeared viable after harvesting, with no signs of discoloration or congestion. All surgical defects were successfully reconstructed with AITFs, which were transposed in place and fixed with a multilayer bolster. Postoperative evaluation revealed that the AITFs achieved full covering of the defects in the posterior frontal sinus wall and cribriform plate. All patients required daily nasal toilette, which included self-administered saline lavage for 6 to 8 weeks. There were no immediate postoperative CSF leaks or other complications. Follow-up (median of 5 months) revealed 100% flap survival and recovery of the mucosa overlying the bony surface of the lateral nasal wall, as well as no events of delayed CSF leak, meningitis, or pneumocephalus within 2 months after the operation.

DISCUSSION

The goal of skull base reconstruction is to reinstate the sterile environment of the brain by preventing CSF leak and air from entering the intracranial compartment. From its inception, reconstruction of the anterior skull base was identified as one of the drawbacks of endonasal surgery. The difficulty of performing dural suturing via an endonasal approach limited the possibility of applying the conventional surgical techniques that are used in open approaches in endoscopic procedures. In addition, the pericranium, which is routinely utilized in open surgery, is no longer available in fully endoscopic procedures. The main reason for the high rates of CSF leaks reported during the early endoscopic era was the lack of well established and widely used local vascularized flaps for endonasal reconstruction.21 After the development of the NSF, the rates of postoperative CSF leak abruptly dropped to a single digit.9,22–26 Still, the main setback in endonasal surgery remained skull base reconstruction in the absence of the NSF. The NSF may
be absent when the tumor involves the septum, when
the flap had been utilized before, when the sphenopalatine
artery had been ligated, or after extensive radio-
therapy when the mucosa is friable and has compromised blood supply.\textsuperscript{27} In those circumstances there are several alternatives that can serve as substitutions for NSFs, including local flaps such as the posteriorly
based inferior turbinate flap and the lateral nasal
wall flap, or regional flaps such as the pericranial and the temporoparietal flaps.\textsuperscript{7,17,18,28,29}

Recently, the AITF flap was introduced for endo-
scopic reconstruction of anterior skull base.\textsuperscript{12,29} The ar-
terial blood supply for this flap is derived from the
AEA.\textsuperscript{13,14,16} The anterior lateral branches of the AEA
carry its blood supply to the anterior half of the inferior
 turbinates, while the posterior lateral nasal branches of
the sphenopalatine artery supply the posterior half of its
mucosa. Anastomosis of the anterior and posterior branches at the middle of the inferior turbinate allows
blood supply through the anterior pedicle to reach the
distal parts of the AITF.\textsuperscript{14,16}

We investigated the formation and application of
AITFs in cadavers and presented a series of patients
whose anterior skull base defects were reconstructed
with this technique. The advantages of this flap are: 1) it is easy to harvest, 2) it is readily available, 3) it can provide adequate coverage of the anterior skull base, and 4) it is associated with minimal morbidity. Our results demonstrated that the AITF was capable of
reaching the anterior third of the sella in all 22 studied
flaps (after extension of the superior incision, i.e., the
extended AITF, in 5 of them).

In our experience thus far, the AITF was used
alone, in combination with a NSF, or in combination
with a posteriorly based inferior turbinate flap. An
adequate seal and 100\% flap survival was achieved in all
cases. The AITF provided complete coverage from the
posterior table of the frontal sinus to the posterior edge of the cribiform plate in all patients.

CONCLUSION

Our cadaveric study and clinical experience estab-
lish the AITF as an alternative to the NSF for anterior
 skull base reconstruction. The flap can cover large por-
tions of the anterior and middle skull base and provide
adequate seal against high flow CSF leaks. Further
studies in high volume medical centers are warranted to
confirm the utility of this flap.

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